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RESEARCH PAPER

Technical efficiency in timber production and effects of other income sources

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Abstract In Norway, as in many other European countries, income from forestry has become marginal to owners' household economies and most employment of forest-owner households is now undertaken off the property. Also, many forest owners have focused increasingly on other revenue-earning activities on their properties, such as providing recreational services. It is a challenge in all kinds of production to find the optimal way of converting inputs into outputs, i.e., to be *technically efficient*. Extent of financial dependency on income from forestry differs between part-time and full-time forest owners. Since the two groups have different livelihood strategies, it is plausible that full-time forest owners have more professional forest management practices. Data for a cross-section of 3,249 active (i.e., harvesting) forest owners were extracted from the 2004 Sample Survey of Agriculture and Forestry representing the year 2003. A stochastic production frontier analysis was applied to evaluate forest management efficiency impacts of important factors including property and owner characteristics, outfield-related and agricultural activities, off-property income and geographical location in central or remote areas. It was found that many forest owners are technically inefficient, and there exist opportunities for improved performance. Off-property income was found to have an estimated negative impact on technical efficiency, the inefficiency arising (weakly) with increasing share of household incomes from outfield activities, and properties in urban centred areas are less efficient than those in remote areas. One policy implication of the study is that a potentially substantial efficiency increase

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might be achieved from allowing small inefficient woodlots to merge into larger units of forestry production. Also, providing support for forest management plans may improve efficiency.

Keywords Cross-sectional analysis · Forest ownership · Stochastic production frontier

Introduction

Forest ownership in Norway has been in transition over the past few decades. Forestry income has become more marginal to owners' household economies, and now amounts in aggregate for only about 2% of the household income in combined forestry and agricultural properties. Most employment is undertaken off the properties. In addition, owners have focused increasingly on other enterprises on the properties, for example building and providing recreational services. Income from such enterprises has gained importance relative to revenue from timber sales, and non-production management objectives have become more important to many owners (Statistics Norway 2005, 2006). Previous studies of non-industrial private forest owners (NIPF) have found their harvesting decisions to be influenced by such non-timber production activities (e.g., outfield activities, amenities) on their properties (e.g., Kuuluvainen et al. 1996), as well as off-property (wage) income (e.g., Løyland et al. 1995). An increased focus on other production strategies is found not only in Norway and other Nordic countries but also in the rest of Europe, and in the USA. Thorough reviews of non-industrial forest owners' harvesting and management behaviour are given in Amacher et al. (2003), Cubbage et al. (2003), and Beach et al. (2005).

An important question to address is how these changes influence the performance of the forest owners as timber suppliers and forest managers. The objective of this study is to examine the technical efficiency of harvesting carried out by active forest owners in Norway, and how this is affected by owner and ownership characteristics.

Technical performance can be measured in several ways. One, which is applied here, is to estimate and analyse the production frontier, which defines the most efficient relationships between inputs and outputs. Considering the forest owners' timber supplies as output, and relating this to inputs in the form of labour, forest area cut and capital stock (the value of standing timber), productivity can be improved in at least two ways. There can be an improvement in technology, e.g., by inventing new logging equipment, represented by an upward shift of the production frontier. Alternatively, various procedures can be implemented—such as extension and advisory services—to ensure that forest owners use the existing technology more efficiently given the feasible technology. Forest owners can either operate on the frontier if they are technically efficient, or beneath the frontier if they are technically inefficient.

Analysis of technical efficiency has two further components. One is to estimate the efficiency, which is as far as many studies go. It is, however, often more interesting to associate variation in technical efficiency with variation in exogenous variables characterising the environment in which the production occurs. In other words, the researcher may investigate which environmental factors (e.g., human capital (experience, age of the decision-maker, education), off-property employment, other

activities on the property) contribute to reduce—and which factors contribute to increase—the degree of technical efficiency. Besides providing information on where potential sources of inefficiency originate, this can suggest policies that may be implemented (or eliminated) to increase overall efficiency levels.

Both non-parametric approaches (e.g., data envelopment analysis) and parametric approaches (e.g., econometric) can be used to analyse efficiency performance (see Coelli et al. 2005 for an overview). In general, parametric approaches are more demanding with regard to data, but have the advantage of taking data noise into account. This study is based on a rich data set of Norwegian forest owners, which makes it possible to estimate a function representing the owners' technology. Therefore, a parametric approach is taken in this study.

There are few econometric studies of efficiency in the forest production and harvesting literature. Carter and Cubbage (1995) measured technical efficiency in the Southern US pulpwood harvesting industry by estimating a stochastic frontier production function. The estimated efficiency scores were then regressed against exogenous variables in a second-stage, to analyse how exogenous factors influence efficiency. There are, however, several serious econometric problems with this two-stage formulation, as outlined for example by Kumbhakar and Lovell (2000, pp. 262–266). A study of the technical efficiency of Polish state timber production and management policies following the transition to more competitive market by Siry and Newman (2001) provided evidence that efficiency is improved by the privatisation of forest operators. A stochastic Cobb-Douglas frontier production function was estimated, but the sources of technical efficiency were not investigated due to lack of data. Recently, Misra and Kant (2005) investigated efficiency and shadow prices of economic, biological and social outputs of village-level organisations of joint forest management in Gujarat, India. They employed a non-parametric multi-output distance function framework.

The frontier technique and efficiency analyses have also to some extent been used within forestry analyses, but on aspects other than harvesting and forest production. Munn and Palmquist (1997) estimated hedonic price equations for a timber stumpage market using parametric stochastic frontier estimation procedures. Yin (2000) measured the productive efficiency of global bleached softwood kraft pulp producers using both stochastic frontier analysis and data environmental analysis. Technical efficiency evaluation of logging contractors using non-parametric analysis (as performed by LeBel and Stuart 1998) and estimated impact of environmental regulation on the profitability and efficiency of paper mills using distance function within the non-parametric approach (e.g., Färe et al. 1993, Chung et al. 1997) are other applied examples.

In the study reported in this paper, the model of Kumbhakar et al. (1991) that estimates the parameters of a stochastic frontier and inefficiency model simultaneously for cross-sectional data is applied for Norway.

Since examinations of the technically efficiency issue of private forest owners' harvesting behavior are virtually absent in earlier studies within forestry, it is difficult to develop firm hypotheses. However, the following propositions have been developed:

1. A high share of off-property income causes high level of technical inefficiency in timber production, and large differences between financial dependency on forestry income cause large differences in technical efficiency between forest owners;

2. An increasing share of total household income from other on-property sources relative to forestry will decrease the technical efficiency of timber production;
3. Since there are generally more (attractive) alternatives for use of human capital in peri-urban than in rural areas, due to a larger market for highly educated labour, the focus on the property resources is greater in rural areas, leading to a higher level of technical efficiency.

The next section outlines the stochastic frontier production function model with inefficiency effects, and the estimation technique applied. The data set of the 2004 Sample Survey of Norwegian Agriculture and Forestry is then described. Next, the empirical results are presented. A discussion and some concluding comments follow.

A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function

The basic concept of technical efficiency are outlined in Fig. 1, which shows the simple example of one input (x) using in producing one output (y) for property A and B.

As given by standard production economics theory, more input will yield more output, but to a decreasing extent so that the (deterministic) production function is concave. Empirically the production function is estimated on the basis of observed input–output values (×) and noise effect. Thus, the production frontier output, can either be above (a positive noise effect) or below (a negative noise effect) the estimated deterministic frontier function. The vertical distance between the estimated (unobserved) stochastic production frontier (⊗) and the observed input–output value (×) is referred to as the *technical inefficiency effect*. The larger the distance is, the larger is by definition the inefficiency.

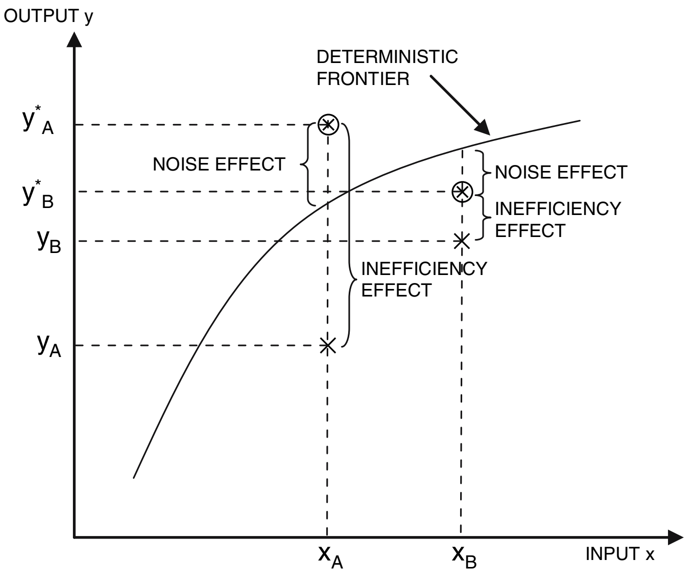

Fig. 1 Stochastic frontier production function (based on Coelli et al. 2005). Subscripts A and B refer to properties A and B, respectively

This simple model can be generalised to the case where firms use several inputs. Unobserved frontier outputs tend to be evenly distributed above and below the deterministic frontier, while the observed outputs tend to lie below the deterministic frontier (but can lie above the deterministic part of the frontier when the noise effect is positive and larger than the inefficiency effect).

The stochastic efficiency model and estimation procedure may be defined more rigorously. The stochastic frontier production function model for cross-section data is:

$$\ln y_i = \phi + \boldsymbol{x}_i'\boldsymbol{\alpha} + v_i - u_i \tag{1}$$

where y_i denotes the timber supply in m^3 of the ith forest property ($i = 1,...,N$), ϕ is the intercept, $\boldsymbol{x}_i'$ is a vector of (functions of) inputs at forest property i, $\boldsymbol{\alpha}$ is a vector of slope coefficients, and $v_i \sim N(0, \sigma_v^2)$ is a random error term. The technical inefficiency effect, u_i, is assumed to be a function of a set of explanatory variables, $\boldsymbol{z}_i$, and of an unknown vector of coefficients $\boldsymbol{\delta}$, to be estimated. Following Kumbhakar et al. (1991) the technical inefficiency effects in the ith property is defined as:

$$u_i = z_i'\delta + \mathrm{w} \tag{2}$$

where the random variable vector $\mathbf{w}$ is defined by the truncation of the normal distribution with zero mean and variance σ_u^2, such that the point of truncation is $-\boldsymbol{z}_i'\boldsymbol{\delta}$, i.e., $\boldsymbol{w} \geq -\boldsymbol{z}_i'\boldsymbol{\delta}$. Within this framework, the values of the unknown parameters in (1) and (2), α, δ, σ_v^2, and σ_u^2, are obtained simultaneously using maximum-likelihood estimation. The estimates are calculated using the computer program FRONTIER 4.1 (see Coelli 1996 for a description of the software).

For the prediction of technical inefficiency effects, it is common to use an output-oriented measure defined as the ratio of observed output to the corresponding stochastic frontier output:

$$TE_i = \frac{\exp(\phi + \boldsymbol{x}_i'\boldsymbol{\alpha} + v_i - u_i)}{\exp(\phi + \boldsymbol{x}_i'\boldsymbol{\alpha} + v_i)} = \exp(-u_i) \tag{3}$$

This expression relies upon that the value of the unobservable u_i being predicted, which is achieved by deriving the expression for the conditional expectation of exp ($-u_i$), conditioned on the observed value of ($v_i - u_i$).

For the deterministic component of Eq. (1), a flexible translog functional form with three input variables is employed:

$$\begin{aligned} \boldsymbol{x}_i = \Big[&\ln x_{1i}, \ln x_{2i}, \ln x_{3i}, 0.5(\ln x_{1i})^2, \ln x_{1i} \ln x_{2i}, \ln x_{1i} \ln x_{3i}, \\ &0.5(\ln x_{2i})^2, \ln x_{2i} \ln x_{3i}, 0.5(\ln x_{3i})^2 \Big]' \end{aligned} \tag{4}$$

The input variables are labour input (x_1), forest area cut (x_2) and capital (x_3). Because there does not exist any comprehensive theory of inefficiencies, the choice of inefficiency effect variables always presents some arbitrariness. Guided by the efficiency literature (referred to in the Introduction), the error component in (2) which captures the effects of technical efficiency has in this study a systematic component $(\boldsymbol{z}_i'\boldsymbol{\delta})$ associated with following exogenous variables:

z_1 = age of the forest owner (yrs)
z_2 = income from outfield related productions (Norwegian kroner, NOK)
z_3 = income from agriculture (NOK)
z_4 = wage income (NOK)
z_5 = debt (NOK)
z_6 = dummy variable for management plan, 1 = plan, 0 = no plan
z_7 = dummy variable for education, 1 = bachelor degree or higher education, 0 = else
z_8 = dummy variable for centrality, 1 = properties close to urban areas, 0 = else

Age of the forest owner, dummy variable for management plan and dummy variable for education are designed to represent the human capital influence on technical efficiency. The income variables of debt and location of the property are socioeconomic attributes that may influence the forest property's level of technical efficiency.

Prior to estimation, output and input variables were scaled to have unit means, such that the first-order coefficients in the model can be interpreted as elasticities of output evaluated at input means.

Sample Data and Specification of Variables

In this study individual cross-sectional data of 3,249 active forest owners (i.e., owners who harvest trees) extracted from the 2004 Sample Survey of Agriculture and Forestry, compiled by Statistics Norway, were applied. These data include results from a postal survey that are linked to data from the tax register, the harvesting register, and the agricultural register (which reports each farmer's support payments including livestock and cropping details). All data are for the year 2003. It should be noted that the sample consists of forest properties that on average are somewhat larger than that of the whole population of forest properties in Norway, which may have implication for the generalisation of the research findings.

The output variable (y) consists of annual timber sales from the forest (ignoring any harvested timber inventories, by assuming ingoing inventories to equal outgoing inventories for the financial year 2003). The labour variable (x_1) has been calculated as the sum of hours worked by contractors and hours worked by the owner, his family or hired labour in 2003, the latter calculated as contractor equivalent hours, i.e., the number of hours a contractor would have used to cut and haul the specific amount of timber. The data set gave no information of hours worked by contractors, so these are estimated as the total costs in NOK involved with contractor work divided by 1,925 NOK/hour. The latter is an estimate of costs per hour of contractors given as the sum of 1,175 NOK/hour for harvester and 750 NOK/hour for forwarder (from Eid and Hoen 2005).

The hectares forest area cut variable (x_2) expresses the area of various types of final fellings in 2003. The capital input variable (x_3) is an estimate of the value of the increment from the forest. It is an expression of the choice faced by forest owner as the increment can either be cut today and its revenue spent on alternative investments or on consumption, or harvesting may be postponed when this is expected to be a better choice. The variable is calculated for each property as the mean weighted price of various timber qualities sold in 2003 multiplied by the maximum sustainable

yield (*MSY*) of the forest resources on the property (i.e., the amount of timber that can be cut without decreasing opportunities for future harvesting). Variation in timber quality on forest land (and thus variation in valuation) between properties will be accounted for using the weighted price. For a few properties there was no information on value or quantity from timber sales; missing values were replaced with the mean value of the sample.

All z-variables used in the study are also taken from the 2004 Sample Survey of Agriculture and Forestry. Table 1 presents some descriptive statistics of the data. A more detailed description of the data and the sampling method is available in Statistics Norway (2004).

Empirical Results from Model Estimation

The translog stochastic frontier production function model with the technical inefficiency effects specified in Eqs. (1) and (2) was statistically tested against more restricted and parsimonious models. The restricted models' hypotheses tests are reported in Appendix A. The preferred model was the above mentioned stochastic frontier translog production function with the technical inefficiency module, and the parameters for this model are reported in Table 2 and discussed below.

Input Elasticities and Scale Economies

As shown in Table 2, estimated elasticities with respect to labour, forest area cut, and capital input all differ from zero at the 1% significance level, and all three have the expected positive sign. The elasticity for labour is the largest, being more than 10

Table 1 Descriptive statistics of the variables for the sample of forest owners in Norway in 2003

Variable	Label	Mean	St. Dev.	Min	Max
Output variable					
Harvesting level (m^3)	y	997.4	2,621.2	2.0	46,068.0
Input variables					
Labour input (hours)	x_1	58.0	141.2	0.1	2,632.5
Forest area cut (ha)	x_2	6.0	14.8	0.01	229.0
Capital value of maximum sustainable yield (NOK [a])	x_3	313,740	821,481	1,476	16,186,055
Efficiency variables					
Age of the forest owner (yrs)	z_1	51.9	11.8	16.0	95.0
Income from outfield related productions (NOK 1000 [a])	z_2	71.0	467.0	0.0	11,814.0
Income from agriculture (NOK 1000 [a])	z_3	54.2	125.9	0.0	2,488.4
Wage income (NOK 1000 [a])	z_4	240.3	269.2	0.0	2,183.1
Debt (NOK M [a])	z_5	1.3	5.3	0.0	132.0
Management plan, 1 = plan, 0 = else	z_6	0.69	0.46	0.00	1.00
Education, 1 = Bachelor degree or higher education, 0 = else	z_7	0.24	0.43	0.00	1.00
Centrality, 1 = Properties in central municipalities, 0 = else	z_8	0.38	0.48	0.00	1.00

[a] NOK 1 = US$ 0.141 (2003)

Table 2 Maximum-likelihood estimates for the parameters in the translog stochastic frontier production function (Eq. (1)), given specification for the technical inefficiency effects, defined by Eq. (2)

Variable	Label	Coefficient	*t*-test	*Sig. level* [b]
Stochastic frontier				
Constant	ϕ	0.103	22.611	***
Labour	α_1	0.908	131.734	***
Forest area cut	α_2	0.075	12.653	***
Capital input	α_3	0.055	10.389	***
(Labour)^2	α_{11}	–0.044	–8.227	***
Labour × Area cut	α_{12}	0.034	8.453	***
Labour × Capital	α_{13}	–0.008	–1.463	
(Area cut)^2	α_{22}	–0.033	–5.201	***
Area cut × capital	α_{23}	0.007	1.312	
(Capital)^2	α_{33}	0.012	2.104	**
Inefficiency model [a]				
Constant	δ_0	–5.197	–6.522	***
Age of forest owner	δ_1	0.017	5.161	***
Income, outfield related productions	δ_2	0.0002	5.188	***
Income, agriculture	δ_3	–0.001	–6.379	***
Wage income	δ_4	0.0004	7.066	***
Debt	δ_5	–0.012	–5.594	***
Management plan, 1 = yes	δ_6	–0.517	–7.520	***
Education, 1 = bachelor or higher	δ_7	0.478	5.487	***
Centrality, 1 = yes	δ_8	0.169	4.346	***
Variance parameters				
	σ_u^2	0.558	7.726	
	γ	0.965	198.264	
Log-Likelihood function				
		963.71		

[a] A negative sign on the coefficients indicates positive impact on efficiency

[b] Significant levels are ** ($P < 0.05$) or *** ($P < 0.01$), based on two-sided *t*-tests

times the elasticities with respect to forest area cut and capital input. As expected, the harvesting level depends strongly on labour used in harvesting.

Scale economies are computed as the sum of all elasticities of input variables. On average, the scale-elasticity is equal to 1.04, indicating that the production function exhibits increasing returns to scale at the means of the data. In other words, the results imply that, on average, the forest owners operate forest properties (or more specifically harvests) that are too small.

Technical Efficiency Level of Harvesting

The average technical efficiency for the sample, estimated with the full flexible model, is estimated as 0.90. For the average forest owner, the harvesting level could have been 10% higher in the investigated year 2003, without requiring more input. However, behind the mean trends there may be large variation between properties, as illustrated in the histogram in Fig. 2. Almost 5% of the forest owners have a technical efficiency level less than 0.75. These have a huge potential for improvements. On the other hand, about 10% of the forest owners are almost technical efficient, with a technical efficiency score of 0.95 or higher.

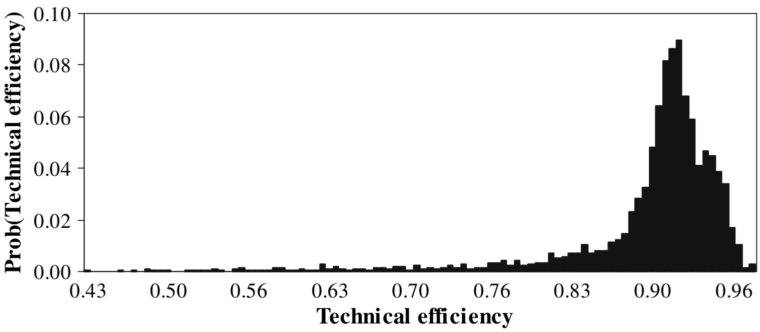

Fig. 2 Distributions of technical efficiencies of harvesting for sample of forest owners in 2003

Factors Explaining the Technical Efficiency Levels

In the lower part of Table 2 the reasons for variations in the efficiency score between forest properties are examined. The age coefficient is positive, which indicates that younger forest owners are more technically efficient than older ones. The positive coefficient of the dummy variable for education indicates that highly educated forest owners are less technically efficient in timber production than the lower-educated ones. These two findings imply that experience (for which age is a proxy) and general knowledge (for which educations is a proxy) unexpectedly have a negative effect on the way the forest is managed and used. The estimated coefficient for debt is found negative, indicating that technical efficiency increases with debt level. As expected, forest management plans contribute to increased technical efficiency. Properties typically rurally located have a higher efficiency level than properties located close to urban areas.

Off-property wage income and income from on-property outfield activities such as recreational services and hunting lead to decreased technical efficiency, while properties combining forestry and agriculture (i.e., properties where income from agriculture is high) have a higher technical efficiency.

Overall Forest Owner and Property Profiles by Efficiency Rankings

In order to examine overall forest owner and property profiles based on efficiency rankings—i.e., how the key owner and property characteristics differ when related to how efficient the property management is – the procedure used by Kompas and Che (2006) was applied. The sample was divided into three sub-groups based on estimated efficiency rankings estimated with the frontier model specified in Eqs. (1) and (2): low (efficiency score less than 83%); medium (83–94%); and high efficiency (greater than 94%). Summary owner and property characteristics from the sample survey dataset of each efficiency groups are given in Table 3.

Regarding owner characteristics, the estimates reveal that age and wage income are significantly higher, while income from agriculture is significantly lower, for the low efficiency group compared to the two other groups. Debt is significantly higher for the high efficiency group compared to the low and medium efficiency groups. The education level is significantly highest for the low efficiency group and lowest for the medium efficiency group.

Table 3 Summary characteristics by efficiency of property group

Characteristics	Efficiency of property group			Significant differences [a]		
	Low (L) <83%	Medium (M) 83–94%	High (H) >94%	L–M	L–H	M–H
Owner characteristics						
Age of the forest owners, yrs	53.6	51.9	51.2	**	***	
Education, 1 = higher	0.33	0.23	0.26	***	**	*
Forest owner, 1 = woman	0.14	0.14	0.16			
Income from outfield related productions, NOK 1000	81.5	71.3	63.2			
Inc. from agriculture, NOK 1000	30.4	55.2	63.9	***	***	
Wage income, NOK 1000	297.5	234.6	232.1	***	***	
Debt, NOK	1.2	1.1	2.2		*	***
Property characteristics						
Harvesting level, m3	783.7	944.2	1355.7		***	***
Harvesting by contractors, 1 = yes	0.99	0.55	0.98	***		***
Forest area cut, ha	6.8	5.7	6.6			
Replanting, 1 = yes	0.32	0.37	0.48	*	***	***
Silviculture, 1 = yes	0.32	0.35	0.40		**	**
Forest management plan, 1 = yes	0.68	0.67	0.78		***	***
Labour hours, forestry	66.6	55.5	64.3			
Labour hours, outfield activities	100.6	105.8	79.5			
Capital value, NOK 1000	352.6	307.7	317.6			
Dairy production, 1 = yes	0.06	0.15	0.08	***		***
Centrality, 1 = properties in central municipalities	0.37	0.38	0.36			
N	316	2390	543			

[a] Significant differences are * ($P < 0.10$), ** ($P < 0.05$) or *** ($P < 0.01$), based on *t*-tests for metric variables and χ^2 tests for categorical (dummy) variables

The estimates regarding property characteristics show that the high-efficiency group has significantly higher harvesting level, conducts more silviculture and is more likely to have a forest management plan compared to the other two groups. The medium efficiency group has a significantly lower share of harvesting conducted by contractors and is more likely to have dairy production compared to the low and high efficiency groups. Finally, the share of replanting increases significantly from the low to the high efficiency groups. For the other variables there are no significant differences between the groups.

Discussion and Policy Implications of the Study

In the introduction, a set of propositions was put forward regarding efficiency. The first proposition related to the potential inefficiency that may arise from off-property income sources has been confirmed: wage income (off-property) has been found to have a significant negative impact on technical efficiency. Also, estimates based on efficiency rankings show that the negative impact of wage income is most frequently found for the low efficiency group. These results relate to the different livelihood strategies chosen by wage-earners compared to self-employed owners, the fact that forest income accounts for a lower share of total household income for wage-earners

and that this group has less time available for efficient production planning. These results are also comparable to the findings of Løyland et al. (1995), that work outside the property is likely to have a negative impact on forest activities.

The second proposition regarding the potential inefficiency arising from an increasing share of household incomes from sources other than forestry is also confirmed by considering the impact from other outfield activities. Causes for this could be that 'pure' foresters have a greater focus on profits from their forests, while the more diversified foresters gain utility from several forestry activities and forest characteristics. Full-time foresters will often also possess more information about the forest resources, supporting better forest management and adaptation. However, estimates based on efficiency rankings show that the possible negative impacts from other outfield activities do not differ between the three groups, as was the case for wage income. Thus the impact from other outfield activities regarding technical efficiency of forest operations is considered weak. Agricultural income affects technical efficiency of harvesting positively and this income is significantly higher for the high and medium efficiency groups. An explanation for this is that agriculture is more separated from forestry production regarding the area used than other on-property production activities. Thus, there are few conflicts related to the joint maximisation of forestry and agricultural production.

The third proposition regarding the greater focus on property resources in rural areas is also confirmed. The sign and magnitude of the estimated coefficient of the centrality dummy clearly indicate that properties in central areas are less efficient than those in remote areas. To some extent this is consistent with the finding of Størdal et al. (2004) that remote regions experience relatively higher harvesting levels in 'boom' periods. This may be a consequence of owners in these regions placing greater weight on utilisation of their forest resources.

This study shows that a noticeable share of the properties is technically inefficient. Thus, one has to keep in mind that some of the findings of 'inefficiency' may be due to owners taking other concerns in forest management into account. For example, shelter wood cutting in urban (or peri-urban) areas occur in order to reduce the potential conflict level that may occur between commercial and multiple-use forestry (Størdal et al. 2004). Still, such behaviour may also have a commercial explanation: if a forest owner is also engaged in other outfield businesses such as tourism or providing recreational services, a more extensive (and less 'technically efficient') forest management may be beneficial from a commercial point of view. Thus, such 'inefficiency' may result from optimising a portfolio of different activities at a specific property. This may explain the (weak) inefficiency impact of income from other outfield activities. On the other hand, there are truly elements of profit-maximising behaviour in this study. This relates to the positive effect of debt and agricultural income on efficiency, as well as the benefits from forest management plans, probably due to increased information about the property's resources.

The finding of increasing returns to scale is not surprising given the relative rigid system for property sales in Norway. Previous studies (e.g., Aanesland and Holm 2000) have drawn attention to the potential gains of releasing some of the constraints for merging the small non-industrial woodlots in Norway.

Although many owners operate inefficiently, one should note that more than 90% of the properties had an efficiency score of 83% or higher, i.e., medium or high efficiency. Still, if the owners can be characterised on the basis of efficiency rankings, the ranking would be as follows. The low efficiency group typically includes an older,

well-educated forest owner with high wage income and with a relatively low harvesting level. The medium efficiency group frequently consist of forest owners that are dairy producers and who are more likely to conduct harvesting themselves. Finally, the high efficiency group can be described as owners with large debts and a high level of harvesting, and who are more likely to have a forest management plan and to conduct silviculture. These results provide a further indication that owners working at the property and having information of the property's resources are working more efficiently.

There are some limitations of the analysis worth mentioning. First, cross-sectional data used to study harvesting behaviour, and the effects other income sources have on the level of technical efficiency between input use and harvesting level, relate to one single year (2003). Thus, preceding or planned harvesting behaviour could not be accounted for. Further, the frontier approach used in this study decomposes deviations from the frontier into inefficiency and noise. Ignoring variation in output caused by uncontrollable factors, often called production risk, can lead to input elasticity and technical efficiency estimates being over-estimated and misleading. To reduce these problems, some studies have included both inefficiency and production risk aspects (e.g., Battese et al. 1997, Kumbhakar 2002, O'Donnell and Griffiths 2006), where deviations from the production frontier are decomposed into inefficiency, risk, and noise. Inclusion of production risk aspects on the problems evaluated in this study is left for future research.

Since large units seem to operate more efficiently than smaller units the policy implication from this study is that there is probably a large potential efficiency gain from allowing small inefficient woodlots to merge into larger units of forestry production. As real prices for timber drop there is an incentive for owners, especially in urban areas with good job possibilities, to take off-property work or to explore further use of other resources on the property. Both are found to reduce efficiency. Releasing some of the constraints that are put on property sales may be a well-targeted means to improve forest management, and increase forestry income. Finally, public support to the further development and refinement of forest management plans may improve efficiency by improving the quality and accessibility of forestry-related information.

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Appendix A

The stochastic frontier production function model with technical inefficiency effects (Kumbhakar et al. 1991), specified in Eqs. (1) and (2) and repeated here:

$$\ln y_i = \phi + \boldsymbol{x}_i'\boldsymbol{\alpha} + v_i - u_i \tag{A1}$$

$$u_i = \boldsymbol{z}_i'\boldsymbol{\delta} + \boldsymbol{w} \tag{A2}$$

can be restricted in several ways. If the variance of the inefficiency effects, σ_u^2, does not differ significantly from zero, the model reduces to a mean response function in which the inefficiency variables enter directly. If $\boldsymbol{z}_i'\boldsymbol{\delta}$ in Eq. (A2) is only a constant

Table A1 Generalised likelihood-ratio tests of hypothesis of the flexible stochastic frontier translog production function specified in equation (A1) and (A2)

Null hypothesis	Log-likelihood	LR statistic	$\chi^2_{0.95}$-value	Decision
Given flexible model	963.71			
$H_0 : \gamma = 0$	839.44	248.55	16.27	Reject H_0
$H_0 : \alpha_{jk} = 0,\ j \leq k = 1, ..., 3$	929.34	68.74	12.59	Reject H_0
$H_0 : \delta_1 = 0,\ l = 0,...,8$	889.13	149.17	16.92	Reject H_0
$H_0 : \delta_1 = 0,\ l = 0,...,8$	955.45	16.52	15.50	Reject H_0

term (i.e., the first z-variable has value one and all the coefficients of the other z-variables are zero), the truncated-normal inefficiency model proposed by Stevenson (1980) is obtained. The half-normal distribution inefficiency model pioneered by Aigner et al. (1977) is obtained when all elements of the $\boldsymbol{\delta}$-vector (including the intercept) equal zero. In addition, one can test if the Cobb-Douglas frontier is an adequate representation for the forest owners, i.e., if the second-order parameters in the flexible translog function are not statistically significantly different from zero.

All the above mentioned null hypotheses are tested using the generalised likelihood-ratio (LR) test, with findings as reported in Table A1. To conduct tests involving the γ parameter, the LR has a mixed χ^2 distribution. The critical values for χ^2_J are taken from Kodde and Palm (1986).

The first hypothesis, H_0: $\gamma = 0$, which specifies that the forest owners are fully technically efficient or that the mean production function is adequate, is strongly rejected. The second hypothesis, H_0: $\alpha_{jk} = 0, \quad j \leq k = 1, \ldots, 3$, that Cobb-Douglas frontier is an adequate representation for the forest owners, is also rejected. The null hypotheses, that the explanatory variables (H_0: $\delta_1 = 0$, $l = 0,...,8$) and that the intercept and the explanatory variables (H_0: $\delta_1 = 0$, $l = 0,...,8$) in the model for technical inefficiency effects have zero coefficients, are also rejected by the data. The preferred model is thus the stochastic frontier translog production function with the technical inefficiency module specified in Eqs. (1 and A1) and (2 and A2).

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